Recent biennial variability of meteorological features in the Eastern Highland Himalayas

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Recent biennial variability of meteorological features in the Eastern Highland Himalayas

Laura Bertolani and Massimo Bollasina
Climate Research Division, Centro Epson Meteo, Milan, Italy.

Gianni Tartari
IRSA-CNR, Milan, Italy.

Abstract. With meteorological data from high altitude surface stations and gridded dataset from NCEP/NCAR Reanalysis, a biennial oscillation over the Eastern Highland Himalayas from 1980 to 1998 is described. This variability concerns air temperature, precipitation, geopotential and wind speed. Evidence is given on the connections between local data and large-scale circulation patterns. The most remarkable oscillating features are found during winter and, in general, the signals are particularly marked on the southern slope of the Himalayan Range. A possible mechanism is explained in terms of a periodicity in surface heat and moisture fluxes. Finally, the peculiarity of the region as a climatic change observatory is underlined.

1. Introduction

The TBO (Tropospheric Biennial Oscillation) is a quasi-biennial periodicity in the course of many variables (e.g., precipitation, atmospheric pressure, sea surface temperature) occurring in the Indian and Pacific regions. It is recognized to be the result of large-scale interaction among sea, land and atmosphere, including tropical-mid-latitude interaction. Its origin is a matter of interesting debates and several theories exist [e.g., *Webster et al.,* 1998]. The interannual variability of the Asian summer monsoon and its relationship with tropical Sea Surface Temperature Anomalies (SSTA) has been outlined by many authors [e.g., *Nicholls,* 1978; *Meehl,* 1987, 1997; *Shen and Lau,* 1995; *Yang and Lau,* 1998; *Chang and Li,* 1999]. Some other works focus on the importance of land-surface processes, especially snow cover and soil moisture over Eurasia [e.g., *Yasunari et al.,* 1991; *Vernekar et al.,* 1995; *Ose,* 1996]. Moreover, the importance of the Tibetan Plateau as an elevated heat source/sink is well described [*Yanai et al.,* 1992; *Murakami,* 1987] and a biennial signal in the tendencies of heat fluxes has been recognized [*Yanai and Tomita,* 1998].

In this paper, a biennial oscillation found in the Eastern Himalayas is highlighted by means of daily (from 1994 to 1998) and monthly (from 1980 to 1998) data recorded at four stations located at high altitudes (above 3800 m). The local climatic features are confirmed and explained by the analysis of large-scale synoptic data available from the National Center for Atmospheric Research (NCAR). The results permit to support and to extend to high altitudes one of the possible mechanisms of TBO, usually described by means of modeling studies.

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2. Data and Methods

The possibility of a biennial periodicity in the course of meteorological parameters is first investigated considering station time series from 1980 to 1998. The synoptic patterns of circulation above the Asian Continent (15°N-45°N, 65°E-110°E) are studied to explain the large-scale origin of the phenomena observed at the stations; numerical values and maps are plotted by means of daily/monthly data available from CDAS-NCAR Reanalysis on a 2.5° x 2.5° grid [*Kalnay et al.,* 1996]. Precipitation gridded data have been collected from the monthly dataset of Climate Prediction Center (CPC) Merged Analysis of Precipitation [*Xie and Arkin,* 1996].

Four stations are considered: the Laboratory-Observatory called "Pyramid", located in the Nepal Highland Himalayas, and three WMO stations, placed in the south-eastern region of Tibet.

The Pyramid meteorological station was set up in 1990 by the Water Research Institute of the Italian National Research Council (IRSA/CNR) and since December 1993 it has run continuously year round. The Pyramid is located in the Khumbu Valley at 5050 m next to Mt. Everest. Its geographical coordinates are 28.0°N 86.8°E.

The Tibetan stations considered are: Tingri (28.6°N 87.1°E, 4302 m), Xigatse (29.3°N 88.9°E, 3837 m) and Xainza (31.0°N 88.6°E, 4671 m). The daily data of the Chinese stations are collected from NOAA global surface summary of daily observations for the period 1994-1998. Monthly summary datasets from NCAR (CAC GLOBAL CEAS summary) are also used for the period 1980-1998.

The following meteorological variables are considered in this analysis: air temperature, precipitation, geopotential and wind speed.

3. Analysis and Results

A variability with a period of 24 months appears in many parameters, such as winter temperatures and wind speed, winter and summer precipitation and geopotential.

The most remarkable feature appears in winter temperature values: during even years, January mean temperatures are warmer than during odd years for all the stations and for the greater number of cases. NCEP/NCAR Reanalysis data point

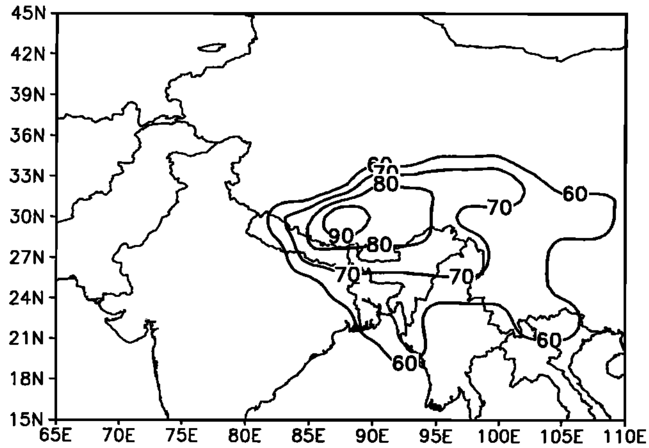

Figure 1. Number of cases (%) January mean temperature at 500 hPa on an even year is higher than those on the following and preceding odd years for the period 1980-1998.

out that this event has occurred with the highest frequency (from 80% to 100%) exactly over the considered area (Fig. 1). The analysis of the difference in the air temperature field at 500 hPa for January (even years minus odd years) highlights a positive area of about 1.5°C over the Eastern Himalayas and the Tibetan Plateau (Fig. 2). Surprisingly, at the Nepalese station (Pyramid) and for the entire five-year period considered, January is warmer than February in even years, while the opposite occurs in the odd ones (Fig. 3). This event is also confirmed by the monthly mean gridded values of temperature at 500 hPa and appears, over the southern slope of the Himalayas, east of 80°E with a frequency of occurrence higher than 85%. To investigate in detail the evolution of the temperature positive anomaly, the daily gridded dataset at 500 hPa has been considered and the five-days averages have been calculated. Three main periods of strong positive anomaly over the Himalayas are evident. The first appears during the second half of December, when the air cooling and sinking motion are establishing over the Continent, the westerly circulation is developing and a positive anomaly, coming

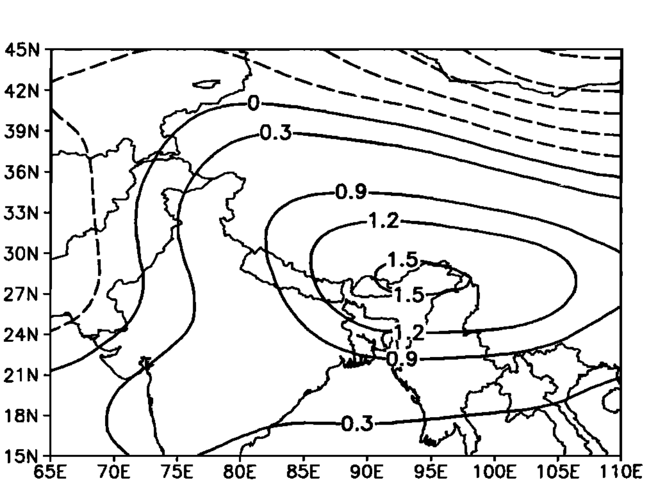

Figure 2. Difference in the air temperature field (°C) at 500 hPa for January (even years minus odd years), calculated considering all the years in the period 1980-1998.

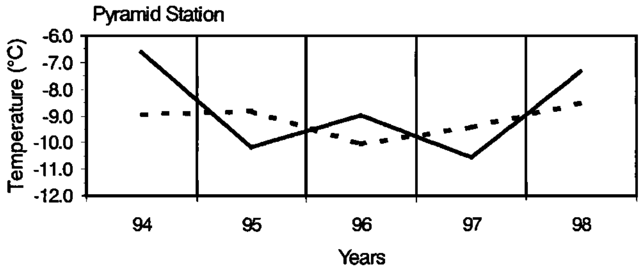

Figure 3. Air mean temperature (°C) at Pyramid from 1994 to 1998. The solid and dashed lines show data for January and February, respectively.

from the Arabian Sea, reaches the Range. Anyway, the monthly mean anomaly results slightly negative (-0.5°C). The strongest episode appears in the first three weeks of January, when winter circulation is fully established. At the beginning of February the anomaly moves southeastward; thus, over the Himalayas, it weakens and, within few days, it reverses (monthly mean of –0.5°C). To confirm this analysis, the time series of temperature anomaly at 500 hPa averaged over the mesh 87.5°E-92.5°E, 27.5°N-32.5°N has been defined as the reference time series. Lead-lag correlations with analogous time series averaged over all the other 5°x5° meshes have been calculated. At –10 days a positive significant correlation (0.4) appears with a center placed in the Arabian Sea moving northeastward to the Himalayas. The +10 days lag map shows that the positive anomaly has reached the Bay of Bengal with a correlation coefficient of 0.6; at +15 days, the correlation over the Himalayas is completely reversed (-0.4).

A biennial variability is also found in the seasonal precipitation amounts, especially in the 90's. In even years, wintertime precipitation is usually more abundant than during odd years along the southern slope of the Himalayas and its vicinity. This is confirmed both by Pyramid and Tingri data and by the Xie-Arkin gridded analysis. The same occurs in summer monsoon precipitation (Fig. 4). However, the oscillation is not as regular as the winter temperature anomaly, probably due to the contribution of local convective phenomena, particularly strong at high altitudes.

To study the circulation features at a synoptic scale, the geopotential field at 500 hPa has been analyzed both for winter and summer monsoon seasons. The map reproducing the winter anomaly (even years minus odd years) shows a large area of positive values centered over the Himalayas (Fig. 5). Monthly maps reveal that January mostly contributes to this configuration, with a high center of about 21 m above the Himalayas. December does not show significant values of the difference, while February has negative values over the Himalayas (-2 m). The mean configuration for the summer monsoon months points out that during even years the "Tibetan High" results slightly stronger (about 5 m) than during odd years.

As a consequence of the winter events, the Sub Tropical Jet Stream undergoes a southern shift and a variation in its intensity. On the synoptic maps at 500 hPa, during even years the Jet Stream, usually located just south of the Himalayas, moves at higher latitudes and weakens, bringing its axis closer to the Range and, thus, causing an increase in wind speed at Pyramid and Tingri (for the last five years available). The

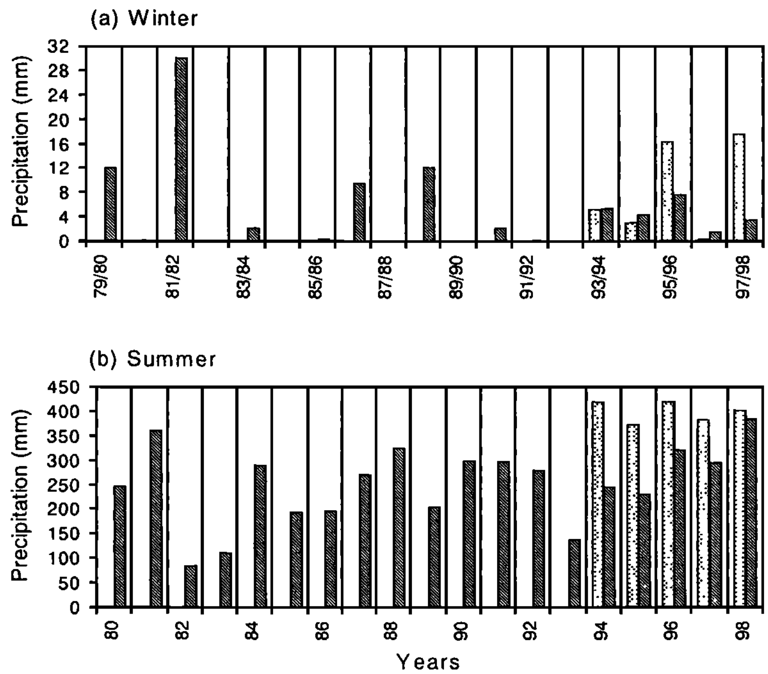

Figure 4. Seasonal total precipitation (mm) for winter (a) and summer (b). The light grey (left) and dark grey (right) rectangles show Pyramid data (1994-1998) and Tingri data (1980-1998), respectively.

anomalous signal of upper-level wind field on South Asia during winter was also observed by *Webster and Yang* [1992].

4. Discussion and Conclusions

The analysis of station data has revealed the existence of a biennial oscillation over the Eastern Highland Himalayas. These results are confirmed by synoptic maps, which point out that the maximal effects of TBO occur in the Himalayan Range and its surroundings during the winter season.

On the basis of the inverse correlation between Eurasian snow cover and summer monsoon rainfall [*Sankar-Rao et al.,* 1996; *Bamzai and Shukla,* 1998], a possible mechanism explaining the observed oscillation, at least over the Himalayas and the Tibetan Plateau, could be described as follows.

After a summer season with scarce precipitation (odd year), the ground of the highlands is covered by a thin layer of snow. The following winter the surface has a lower albedo, there is a lower consumption of solar heat to melt snow and, therefore, the air cooling due to the surface heat sink and the consequent subsident motion are less intense. This determines the weakening of the thermal blocking anticyclone at ground level over the Himalayas and the Tibetan Plateau, the rising of the geopotential at 500 hPa and the weakening and the northerly shift of the Sub Tropical Jet Stream. Westerly zonal circulation is modified and an anomalous trough appears, which drives warm and humid air coming from the Arabian Sea toward the Eastern Himalayas, increasing precipitation. The warm events begin at the end of December and become particularly intense during January, when the winter circulation is completely established and, consequently, the anomalies in the westerlies are more pronounced. Daily synoptic maps of geopotential at 500 hPa show at least one deep trough passing over the south-eastern Himalayas region in January. The year by year variability in the occurrence of each strong event determines the spread of the anomaly over the three-weeks period. Station daily records of temperature validate this large-scale view, more evident at the highest stations (mainly at the Pyramid, being on the windward side of the Range). For all stations, in the even years, it is possible to recognize at least one unusual warm episode in January. At the end of winter (February), the albedo due to the accumulated new snow produces a cooling effect on the air and a consequent consolidation of the subsident motion. Gridded data reveal that in March the exceeding winter snow is completely melted and both the negative temperature anomaly and the negative geopotential anomaly disappear. After that, convective activity is facilitated and in the summer

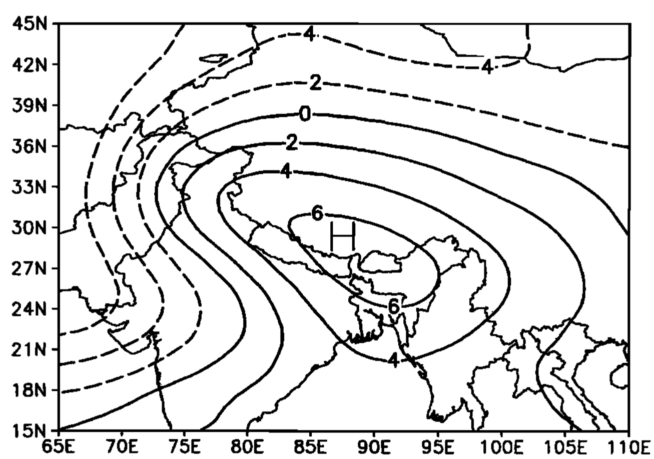

Figure 5. Difference in the geopotential field (m) at 500 hPa for winter (even years minus odd years), calculated considering all the years in the period 1980-1998.

monsoon season the "Tibetan High" results slightly stronger than the preceding and the following year, with its higher positive anomaly over the Range. This brings more abundant precipitation, mainly on the windward side of the Range. The abundance of snow cover and soil moisture prevents the heating of the ground during the following winter (odd year), the stronger thermal anticyclone placed over the Tibetan Plateau protects this area from southern warm maritime air, winter precipitation is less abundant, the "Tibetan High" is weaker and the summer monsoon precipitation is lesser too. So the cycle repeats.

The biennial oscillation observed over the Himalayas and its surroundings was not found in the 70's. It started in 1982 and gained a strong periodicity only in the last decade, with the winter anomalies punctually repeated. In 1982-1983 a particularly anomalous warm episode is evident in NINO 3 SSTA time series [*Webster at al.,* 1998], as well as in the tropical circulation [*Ropelewski et al.,* 1992]. This event could have given the starting phase to the oscillation. Of course, the oscillation could have a different periodicity on a longer period (near to the peak of 2-3 years, see *Tomita and Yasunari,* 1996; *Meehl,* 1997). The biennial variability under discussion is clearly modulated by land-surface processes, though largely depending on synoptic forcing as SSTA, which provide more or less moisture and influence the meridional temperature contrast between land and ocean. Thus, SSTA would give rise to an oscillation of the same sign of that proposed. These results suggest that TBO is an intrinsic oscillation of monsoon circulation and emphasize the role played by the extra-tropical interaction.

Meehl [1997] recognized different structures of the geopotential field at 500 hPa and surface heating for three years (1987-1989) centered on a strong monsoon year (1988). Many features of his work can be found in the theory exposed above, mainly the configuration of geopotential and the variation of position of the 500 hPa trough in successive years.

General Circulation Model (GCM) experiments [e.g., *Vernekar et al.,* 1995; *Ogasawara et al.,* 1999] assessed the great influence of snow cover on surface heat fluxes and precipitation. *Vernekar et al.* [1995] also found that the effect on air temperature was particularly enhanced over the Tibetan Plateau.

From this study emerges the importance of station datasets in the comprehension of the mechanisms of TBO, that reveals clear features also at high altitudes. On the other hand, data provided by a GCM have an overall intrinsic limit of reliability and detail in area with complex orography.

Point measures of snow cover depth are necessary to assess the role of surface processes with more certainty. Unfortunately, the operating meteorological stations located in that remote site are very scarce, especially on the southern slope of the Range, and a detailed and complete description of the phenomenon is not simple. Anyway, this attempt could be an incentive for the planning of future researches to be developed at high altitudes. One of the aims could be the study of the effects of TBO on the long-range transport of pollutants deposited on snow cover in the Highland Himalayas.

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L. Bertolani and M. Bollasina, Climate Research Division, Centro Epson Meteo, via Pisa 250, 20099 Sesto S. Giovanni, Milan, Italy. (e-mail: meteo@comm2000.it)

G. Tartari, Istituto di Ricerca sulle Acque, Consiglio Nazionale delle Ricerche, via della Mornera 25, 20047 Brugherio, Milan, Italy. (e-mail: tartari@server-mi.irsa.rm.cnr.it)

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